**Climate Science Foundations – Module 1**

**Slide . Climate Change and One Health: The Science of Global Climate Change**

**Slide . Learning Objectives**

Throughout this module, we aim to achieve four (4) learning objectives. These include:

1. Being able to differentiate weather and climate processes
2. Explain the relationship between greenhouse gas emissions and global climate change
3. Describe evidence of global climate change
4. Discuss how global climate models are used to understand global climate change

**Slide . What is Climate Change?**

**Slide . Images that Come to Mind When We Say “Climate Change”**

**Slide . Important Terminology**

**Slide . [Temperature Time Series, Demonstrating Variability]**

**Slide . Temperature Anomalies**

**Slide . Greenhouse Effect**

When energy from the sun reaches the Earth, the planet absorbs some of this energy and radiates the rest back to space as heat.

The greenhouse effect is a process that occurs when energy – in the form of heat from the Sun – is trapped close to Earth’s surface by greenhouse gases. These gases are important; they can be thought of as a blanket that wraps the earth in warmth.

**Slide . Trends in Atmospheric CO2, 1968 – 2022**

Monthly mean CO2 measured at Mauna Loa Observatory --- longest record of direct CO2 measurements in the atmosphere

Every monthly mean is the average of daily means, which are based on hourly averages.

The RED lines represent the monthly mean values. The black line represents the same, after correcting for seasonal cycle.

**Slide . Evidence of Relationship Between CO2 and Global Temperature**

So, what evidence do we have that there is a relationship between CO2 and global temperature? Here, we are looking at yearly temperatures compared to the 20th century average (this is shown in the blue bars, red bars) from 1880 to 2019. Overlaid on top of this (grey line) are atmospheric carbon dioxide (CO2) concentrations.

**Slide . Global Warming Potential (GWP) of Primary Greenhouse Gases**

Greenhouse gases trap infrared radiation near the surface, warming the climate.

These gases differ in their ability to absorb energy, that is, they have various radiative efficiencies. They also differ in their atmospheric residence times. Each gas has a specific global warming potential (GWP), which allows comparisons of the amount of energy the emissions of 1 ton of a gas will absorb over a given time period, usually a 100-year averaging time, compared with the emissions of 1 ton of CO2.

CO2 remains by far the most important positive anthropogenic driver, with methane next most significant; anthropogenic methane stems from such sources as fossil fuel extraction, natural gas pipeline leakage, agriculture, and landfills

GWPs are multipliers applied to greenhouse gases such as methane (CH4) and Nitrous Oxide (N2O) to equate the impact they have on the Earth’s temperature with that of Carbon Dioxide (CO2).

For instance, pound for pound, the comparative impact of CH4 is about 30 times greater than CO2 over a 100-year period. In the AR6 report, an additional GWP for methane has been included to differentiate between methane which originates from fossil fuel sources, and methane from non-fossil fuel sources, like agriculture.

**Slide . Global Greenhouse Gas Emissions, 1990-2019**

This figure shows worldwide emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated gases from 1990 to 2019.

Include examples of sources for each emission type (e.g., naturally-occurring methane, agricultural methane)

In 2015, estimated worldwide emissions from human activities totaled nearly **47 billion metric tons of greenhouse gases**, expressed as carbon dioxide equivalents. This represents a **43 percent increase from 1990** (see Figures 1 and 2). These numbers represent net emissions, which include the effects of land use and forestry.

Between 1990 and 2015, global emissions of all major greenhouse gases increased. Net emissions of carbon dioxide increased by 51 percent, which is particularly important because carbon dioxide accounts for about three-fourths of total global emissions. Methane emissions increased the least—17 percent—while emissions of nitrous oxide increased by 24 percent. Emissions of fluorinated gases more than tripled.

Energy production and use (including fuels used by vehicles and buildings) represent the largest source of greenhouse gas emissions worldwide (about 75 percent of the total in 2015), followed by agriculture (12 percent in 2015) (see Figure 2). While land-use change and forestry represent a net sink for emissions in the United States, absorbing carbon dioxide and offsetting emissions from other sources (see the [U.S. Greenhouse Gas Emissions](https://www.epa.gov/climate-indicators/climate-change-indicators-us-greenhouse-gas-emissions) indicator), these activities are a net source of emissions on a global scale, largely because of deforestation.[1](https://www.epa.gov/climate-indicators/climate-change-indicators-global-greenhouse-gas-emissions)

* Carbon dioxide emissions are increasing faster in some parts of the world (for example, East Asia and the Pacific) than in others (see Figure 3). The majority of emissions come from three regions: East Asia and Pacific, Europe and Central Asia, and the United States, which together accounted for 74 percent of total global emissions in 2018.

**Slide . Modeling Global Climate Change**

With this knowledge of the amount of greenhouse gases in our atmosphere, we can model global climate change

Source: <https://dept.atmos.ucla.edu/alexhall/downscaling>

**Slide . Understanding Climate Model Projections**

[Climate models](https://www.carbonbrief.org/qa-how-do-climate-models-work) are one of the primary means for scientists to understand how the climate has changed in the past and may change in the future. These models simulate the physics, chemistry and biology of the atmosphere, land and oceans in great detail, and require some of the largest supercomputers in the world to generate their climate projections

A global climate model (GCM) is a complex mathematical representation of the major climate system components (**atmosphere, land surface, ocean, and sea ice**), and their interactions. Earth's energy balance between the four components is the key to long-term climate prediction.

Earth’s energy balance between the **four components** is the key to long-term climate prediction.  The main climate system components treated in a climate model are:

* The atmospheric component, which simulates clouds and aerosols, and plays a large role in transport of heat and water around the globe.
* The land surface component, which simulates surface characteristics such as vegetation, snow cover, soil water, rivers, and carbon storing.
* The ocean component, which simulates current movement and mixing, and biogeochemistry, since the ocean is the dominant reservoir of heat and carbon in the climate system.
* The sea ice component, which modulates solar radiation absorption and air-sea heat and water exchanges.

Climate Model. Computer simulation that characterizes the Earth’s climate system by using mathematical equations to represent interactions of important climatic drivers like the atmosphere, oceans, land surface, and ice. They are used to study past climate or predict future climate.

Climate Forcing.

The Earth’s surface temperature depends on this balance between incoming and outgoing energy. Average conditions tend to remain stable unless the Earth experiences a force that shifts the energy balance. A shift in the energy balance causes the Earth’s average temperature to become warmer or cooler, leading to a variety of other changes in the lower atmosphere, on land, and in the oceans.

Downscale.

Until recently, there were two main types of downscaling methods: dynamical methods, which involve the use of high-resolution regional climate models, and statistical methods, which use mathematical relationships between local climate variables and their large-scale predictors. Dynamical downscaling is highly physically realistic, but computationally very expensive, making comprehensive regional studies impractical. Statistical downscaling is computationally cheap, but not necessarily physically realistic.

**Slide . Coupled Model Intercomparison Project (CMIP)**

**CMIP** A group of comparable climate model simulations. Each model is slightly different from another; the ensemble average is expected to perform better than an individual model.

Model Ensemble. We know that a climate model is a numerical representation of the climate system, meaning it does not perfectly describe the system. The description of the physical laws governing the climate system differs between models. The model complexity differs between climate models, some models include more processes that others. This means that all climate models will give different results. The size of these differences can be large or small depending on model, region, season, variable etc. A model may perform well for some region/ season/ variable and worse for another, while another model performs well for yet another region/season/variable. The usual way to handle these differences is to use model ensembles.

Sources: <https://www.lancaster.ac.uk/data-science-of-the-natural-environment/blogs/how-to-use-ensembles-of-climate-models>

The goal of [CMIP](https://www.carbonbrief.org/qa-how-do-climate-models-work) is to generate a set of standard simulations that each model will run. This allows results to be directly comparable across different models, to see where models agree and disagree on future changes. One of the main sets of simulations run by models are future climate scenarios, where models are given a common set of future concentrations of greenhouse gases, aerosols and other [climate forcings](https://www.carbonbrief.org/qa-how-do-climate-models-work) to project what might happen in the future.

**CMIP6** Coordinated efforts from CMIP. Contains output from ~100 distinct climate models, produced by 49 modeling groups.

**Climate forcing** is a measure of the ‘radiative forcing’ (or HEATING EFFECT) caused by greenhouse gases in the atmosphere.

**Radiative forcing –** the amount of warming or cooling that affects global energy balance; It’s calculated in watts/square meter, which represents the size of the energy imbalance in the atmosphere

**Of the greenhouse gases in the atmosphere**, CO2 accounts for the LARGEST SHARE of radiative forcing and continues to grow at steady rate.

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**Slide . Climate Scenario Modeling**

The energy modelling community has developed a new set of emissions scenarios driven by different socioeconomic assumptions, These are the “[Shared Socioeconomic Pathways](https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change)” (SSPs). A number of these SSP scenarios [have been selected](https://www.geosci-model-dev.net/9/3461/2016/) to drive climate models for CMIP6. A set of scenarios were chosen to provide a range of distinct end-of-century climate change outcomes.

* SSP1-1.9: ​Holds warming to approximately 1.5C above 1850-1900 in 2100 “after slight overshoot” and implied net-zero CO2 emissions around the middle of the century.
* SSP1-2.6: Stays below 2C warming with implied net-zero emissions in the second half of the century.
* SSP2-4.5: (optimistic) Approximately in line with the upper end of [combined pledges](https://climateactiontracker.org/global/cat-thermometer/) under the [Paris Agreement](https://www.carbonbrief.org/interactive-the-paris-agreement-on-climate-change). The scenario “deviates mildly from a ‘no-additional climate-policy’ reference scenario, resulting in a best-estimate warming around 2.7C by the end of the 21st century”.
* SSP3-7.0: (middle-of-the-road scenario) A medium-to-high reference scenario resulting from no additional climate policy, with “particularly high non-CO2 emissions, including high aerosols emissions”.
* [SSP5-8.5](https://www.carbonbrief.org/explainer-the-high-emissions-rcp8-5-global-warming-scenario): (worse case scenario) A high reference scenario with no additional climate policy. Emissions as high as SSP5-8.5 are only achieved within the fossil-fueled SSP5 socioeconomic development pathway.

**Slide . The Evidence for Climate Change: What do we know?**

We’ve looked at how we can model the Earth’s energy balance to understand what that might mean for global climate change. But, let’s review what evidence we have for such change.

**Slide . Intergovernmental Panel on Climate Change (IPCC)**

First, we would be remiss if we didn’t discuss the Intergovernmental Panel on Climate Change, or the IPCC, and its role in climate science. The IPCC was created in 1988 to provide policymakers with **regular scientific assessments on climate change**, its implications and potential future risks, as well as to put forward adaptation and mitigation options. It is a coalition of **volunteer scientists from around the globe**.

Through its assessments, the IPCC determines the state of knowledge on climate change.

These assessments are large reports that synthesize the current climate science and are released, on average, every six to seven years

**Slide . “It is unequivocal …”**

In Fall 2021, the IPCC released it’s 6th assessment. It utilized more than 14,000 peer-reviewed studies. The conclusions are stark and demand attention:

“It is unequivocal that human influence has warmed the atmosphere, ocean, and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred.”

**Slide . Human Influence and a Warming Planet**

The rapid changes in these systems are due to human influence. In this graph showing reconstructed climate and observed climate, we can see unprecedented warming in the last 2000 years. Around 1850 (corresponds to the Industrial Revolution), warming substantially increased.

Each of the last four decades has been successively warmer than any decade that preceeded it since 1850.

* Global surface temps in the first two decades (2001 – 2020) was nearly 1°C higher than the time period 1850-1900.
* Global surface temps were 1.09 °C higher in 2011-2020 than 1850 – 1900. – these changes were larger over land than the ocean

**Slide . Human Influence and a Warming Planet**

And, the science now allows us to look more specifically at the human contribution by running models that simulate human and natural contributions to global climate change (so, GHG emissions from human activity and natural sources like solar and volcanic activities). This is shown in brown. We can then compare the change in global surface temperatures in model simulations that \*only\* include natural sources (solar and volcanic), shown in green.

We can see clearly that humans are driving much of the global surface temperature rise. And, this becomes dramatically apparent around the 1970s, when the two model estimates diverge. We can see that the decade from 2010-2020 was the **HOTTEST DECADE IN 125,000 YEARS**

**Slide . Observed Warming Driven by Greenhouse Gas Emissions from Human Activities**

Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling

Included in this figure are measures of natural factors (small black vertical bar) and internal variability of the models (larger black bar). However, these are minimal in their contribution to the overall warming and cooling effects we see from human influence and greenhouse gases

**Slide . Human Influence as a Main Driver**

The signs of climate change are unequivocal at the global scale and are increasingly apparent on smaller spatial scales. The **high northern latitudes show the largest temperature increase**, with clear effects on sea ice and glaciers. The warming in the tropical regions is also apparent because the natural year-to-year variations in temperature there are small. Long-term changes in other variables such as rainfall and some weather and climate extremes have also now become apparent in many regions.

Human influence is a main driver of some of the impacts we are seeing today. In particular, we have observations that …

* Extreme heat that is becoming more common – including in parts of the world that didn’t experience extreme heat – and the heat events are more intense. Meaning, the temperatures are getting higher
* Since the 1970s, there’s been a well-documented trend in ocean temperatures increasing. This is associated with ocean acidification – where the reduction of seawater pH is a consequence of the oceans absorbing large amounts of CO2.
* Changes in the frozen areas of the planet: Specifically
  + Global retreat of glaciers since the 1990s
  + 40% decrease in Arctic sea ice since 1979

**Slide . State of Climate Science – AR6**

Human influence on global climate is *unequivocal*.

The scale of recent changes across the climate system is *unprecedented*.

Evidence of observed changes in extremes has strengthened since AR5 (2013).

* Every world region is projected to increasingly experience concurrent and multiple changes. Even a difference between 1.5oC and 2oC can lead to pronounced changes. Strong, rapid, and sustained reductions in emissions required now.
* Changes due to past GHG emissions are irreversible for centuries to millennia.

**Slide . Future Emissions Lead to Future Additional Warming**

**Slide . “Unless there are immediate, rapid, and large-scale reductions in greenhouse gas emissions, limited warming to 1.5 C will be beyond reach”**

Deliberate removal of carbon dioxide (CO2) from the atmosphere could reverse (i.e. change the direction of) some aspects of climate change. However, this will only happen if it results in a net reduction in the total amount of CO2 in the atmosphere, that is, if deliberate removals are larger than emissions. Some climate change trends, such as the increase in global surface temperature, would start to reverse within a few years. Other aspects of climate change would take decades (e.g., permafrost thawing) or centuries (e.g., acidification of the deep ocean) to reverse, and some, such as sea level rise, would take centuries to millennia to change direction

**Slide . Future Emissions Lead to Future Additional Warming**

**Slide . Temperature**

With every increment of global warming, changes get larger in regional mean temperature, precipitation, and soil moisture. Let’s look here at temperature.

Warming at 1oC affects all continents and is generally larger over land than over the oceans in both observations and models.

We see three simulated changes: 1.5oC, 2oC, and 4oC. Across warming levels, \*land areas\* warm more than ocean areas, and the Arctic and Antarctica warm more than tropics.

**Slide . Precipitation**

Here, we have similar simulations, but looking at annual mean changes in precipitation.

Precipitation is projected to **increase over high latitudes**, **the equatorial Pacific, and parts of the monsoon regions**, but **decrease over parts of the subtropics and in limited areas of the tropics**.

**Slide . Soil Moisture**

Lastly, we look at soil moisture. Soil moisture is important because it is one of the indicators of drought. We see across warming levels, changes in soil moisture **largely follow changes in precipitation** but also show **some differences due to the influence of evapotranspiration**

**Slide . Extreme Event Attribution**

This *BAMS*special report presents assessments of how human-caused climate change may have affected the strength and likelihood of individual extreme events.

The tenth edition of the report, *Explaining Extreme Events in 2020 from a Climate Perspective*, presents 18 new peer-reviewed analyses of extreme weather from across the world during 2020. It features the research of 89 scientists from nine countries looking at both historical observations and model simulations to determine whether and by how much climate change may have influenced particular extreme events.

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